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# Sequential aiming with one and two limbs: Effects of target size

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## Abstract

It is well reported that movement times to the first target in a two-target sequence are slower than when a single target response is required. This one-target advantage has been shown to emerge when the two-target sequence is performed with the same limb and when the first and second segments within the sequence are performed with different limbs (i.e., when there is a switch between limbs at the first target). The present study examined the functional dependency between response segments in both single and two limb sequential aiming by varying the accuracy demands at the first and second target. Results revealed that, for both one and two limb conditions, the one-target advantage was present with large first targets but not with small first targets. Additionally, when the first target was large and the second target was small, spatial variability at the first target was significantly less (or constrained more) in both one and two limb conditions compared to conditions requiring only a single target response. These findings suggest that similar principles underlie the one-target advantage in both single and two limb sequential movements.


Key words: One-target advantage; Sequential aiming; Movement integration

## 1. Introduction

While the work of Henry and Rogers (1960) motivated an extensive body of research aimed at understanding the relationship between reaction time and the number of response elements (e.g., Klapp, 1995, 2003; Khan, Lawrence, Buckolz & Franks, 2006; Sternberg, Monsell, Knoll & Wright, 1978), researchers have also focused their efforts on understanding how movement times are affected by the number of targets in an aiming sequence (Adam et al., 2000; Chamberlin & Magill, 1989; Khan, Mottram, Adam & Buckolz, 2010; Helsen, Adam, Elliott & Buekers, 2001; Lavrysen, Helsen, Elliott, & Adam, 2002). Collectively, this body of research has indicated that individual segments in a targeted sequence are not prepared and executed independently (Adam et al., 2000; Khan et al., 2010). When the number of targets is known in advance, the preparation and execution of the targeted sequence is influenced by the properties of the individual segments as well as the relation between segments.

The interdependency between response segments in a targeted sequence has been explained via two hypotheses. The movement constraint hypothesis (Fischman & Reeve, 1992) is based on the assumption that the variability of movement endpoints accumulates from one target to the next. Hence, movement to the first target must be constrained so that the accuracy demands at the second target are met (Sidaway, Sekiya & Fairweather, 1995). The constraining of movement endpoints at the first target is achieved through more precise movement planning and/or feedback processing during movement execution (Khan et al., 2010).

Adam et al.'s (2000) movement integration hypothesis poses that segments are programmed and stored in a buffer prior to response initiation. In order to facilitate a smooth and efficient transition between elements, the implementation of the second element is performed online concurrent with the execution of the first. This online implementation results in increased cognitive control during the production of the first element which leads to (dual-task) interference (e.g., Oliveira & Ivry, 2008). Hence, while the implementation of the second segment during the first segment facilitates the transition between segments, the increased cognitive processing load during movement execution results in a lengthening of MT to the first target.

Most research surrounding the one-target advantage has focused on single limb movements with findings revealing the one-target advantage to be robust regardless of manipulations of vision, hand preference and hand used (Adam, Helsen, Elliott & Buekers, 2001; Lavrysen et al., 2002). More recently, the robustness of the one-target advantage was extended to include movements involving two limbs (Khan et al., 2010). Here participants performed single target movements, two target movements with one limb, and two target movements in which limbs were switched at the first target. The results revealed a one-target advantage for both the single and two limb conditions. This finding had two important theoretical implications. Firstly, the presence of the one-target advantage for two-limb movements would seem to be inconsistent with the movement constraint hypothesis. This is because the start position of the limb for the second movement was fixed and hence did not depend on the variability of endpoints at the first target. Hence, accuracy of the second segment should not have depended on the accuracy of the first segment. Secondly, Khan et al. reported that the magnitude of the one-target

advantage was similar for both the single and two limb conditions. This finding implied a central locus of interference as the underlying cause of the one-target advantage (i.e., retrieval of a motor program from a motor buffer). If the one-target advantage was due to peripheral factors (i.e., muscular organisation of the limb being adjusted and readied for a second movement), one would not expect the one-target advantage to emerge in the two limb condition where movements were performed by distinct effectors.

Whilst the one-target advantage has been shown to be robust, it does not emerge when the accuracy demands at the first target are relatively high (Adam et al., 2000). Movements to a small target are characterised by relatively long pause times between response segments thereby functionally separating the movements to first and second targets (Adam & Paas, 1996; Adam et al., 1995; Adam et al., 2000; Rand & Stelmach, 2000). Hence, with small targets, the principles underlying the movement integration hypothesis and movement constraint hypothesis do not apply since the two segments are controlled as separate units.

The purpose of the present study was to further investigate the functional dependency between response segments when the first and second segments were performed with separate limbs. We used a similar paradigm to Khan et al. (2010) in which participants performed single target movements, two target movements using the same limb, and two target movements in which the limb was switched at the first target (i.e., a two limb task). In addition, the sizes of both the first and second targets were manipulated. With regards to the size of the first target, we expected that consistent with past research the one-target advantage would emerge for both the single and two limb conditions when the first target was large. When the first target was small, we expected

that the one-target advantage would not emerge when the two target movement was performed with a single limb because the accuracy demands result in the two segments being controlled as separate units (Adam & Paas, 1996; Adam et al., 1995; Adam et al., 2000; Rand & Stelmach, 2000). Of particular interest was whether the one-target advantage would emerge when the first target was small under the two limb condition. On one hand, one might expect that the one-target advantage would still emerge since the starting point of the second segment should not depend on the accuracy demands of the first segment. In other words, using different effector systems for the first and second segments may preserve functional dependency between the two segments under high accuracy constraints. On the other hand, based on the underlying assumption of the MIH that the one-target advantage emerges from an overlap of demands on central resources (Adam et al., 2000; Khan et al., 2010), the high accuracy demands at the first target would have a similar effect on both the single and two limb conditions. Hence, similar to the single limb condition, the one-target advantage would not emerge in the two limb condition. This finding would again point to a central locus of interference as the underlying cause of the one-target advantage.

With regards to the size of the second target, Sidaway et al. (1995) have shown that variability at the first target was reduced when the accuracy demands at the second target were increased. They attributed this reduction in variability at the first target to participants constraining their movement in order to be accurate at the second target. We expected to replicate this result when movements to both targets were performed with the same limb. However, it was expected that when the limb was switched at the first target, the size of the second target would have no impact on variability at the first target since

the start of the second segment does not depend on the endpoint location at the first target.

## 2. Method

### *2. 1. Participants*

Participants were 24 (18 men, 6 women; *M* age = 21 years, *SD* = 3 years, age range = 19-30 years) self-declared right hand dominant volunteers who reported normal or corrected to normal vision and were naïve to the experimental hypotheses. Consent forms were signed prior to the start of the experiment, and the study was carried out according to the ethical guidelines stated by the Ethics Committee of the School of Sport, Health and Exercise Sciences, Bangor University, for research involving human participants.

### *2. 2. Apparatus*

Participants were seated at a table 75 cm above the ground. Aiming movements were performed on a computer monitor (19 inch) that was mounted horizontally and faced upwards in a cavity cut out from the table top. A sheet of plexi-glass 5 mm thick covered the monitor surface and was flush with the table top. Six circular targets were presented on the monitor arranged in sets of 3 pairs along the participants' midline (see Figure 1a). The distance between each target in a pair was 40mm (centre to centre), and the distance between each pair was 100mm (centre to centre). The most distal targets were the start positions. The middle targets were designated as target 1 and the most proximal targets as target 2. The aiming tasks were performed under four target size conditions (see Figure 1b). In the Small-Small condition, both targets were 5 mm in diameter while in the Large-Large condition, both targets were 20mm in diameter. In the

Small-Large condition, the first target was 5mm while the second target was 20mm, and vice versa in the Large-Small condition (Small Targets Index of Difficulty = 5.3 bits, Large Targets Index of Difficulty = 3.3 bits [Fitts, 1954]). In all four target conditions, the start position always consisted of a 5mm diameter circle.

Participants performed the tasks using a pointed stylus. The position of the stylus was recorded from a small infrared-emitting diode (IRED) that was secured at the end of the stylus. The IREDs were monitored using an Optotrak **(**Northern Digital Inc**)** three-dimensional movement analysis system at a sampling rate of 500 Hz (resolution 0.01mm).

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Insert Figure 1 here

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*2. 3. Procedure*

Participants performed 3 tapping aiming tasks. For each task, participants placed the stylus in their right hand on the right start position and the stylus in their left hand on the left Target 1 (see Figure 1a). The different tasks are depicted in Figure 1 c. In the One target task, participants moved the stylus in their right hand from the start position to tap down at Target 1. The stylus in their left hand remained stationary at Target 1. In the Two target: Single limb task, participants moved the stylus in their right hand from the start position to tap down at Target 1 and then again at Target 2. Again, the stylus in their left hand remained stationary on Target 1. In the Two target: Two limb task, participants moved the stylus in their right hand from the start position to tap down at Target 1 and then moved the stylus in their left hand from its position on Target 1 to tap

down on Target 2. Participants were told not to start the second movement until the first had been completed, but to make this changeover as quick as possible.

At the beginning of each trial, participants were presented with a warning tone which was then followed by a stimulus tone after a 1500-2500 ms variable foreperiod. Participants were instructed to react and perform the movement(s) as quickly as possible. Each participant completed 240 trials. This consisted of 60 trials in each of the 4 target size conditions. For each target size condition, 20 trials were performed in each of the One target, Two target: Single limb, and Two target: Two limb tasks. The order of the target size conditions were counterbalanced between participants while the order of the three aiming tasks was counterbalanced within the target size conditions**.**

*2. 4. Data Reduction*

The 3D position data from the Optotrak were filtered using a second order, dual-pass Butterworth filter with a low pass cut-off frequency of 16Hz. Position data were then differentiated to obtain velocity information. Peak resultant velocity was identified for movements to each target. The start (i.e., stylus lift off) of the movement to the first target was identified from working back from peak velocity to locate the first point at which velocity in the vertical direction (i.e., z-axis) was less than 15mm/s. The end (i.e., stylus touch down) of the first movement was the point at which velocity in the vertical direction fell below 15mm/s[1] following peak velocity. This process was repeated for the start and end locations of the second movement. At the end of each movement segment,

[1] The velocity in the vertical direction was used to locate the start and end of movements since occasional sliding of the tip of the stylus on the table top at target touch down made it difficult to accurately locate velocity zero line crossings in the horizontal plane.

position coordinates were recorded in the primary direction of the movement (i.e., x-axis) and perpendicular to the primary movement (i.e., y-axis).

*2.5. Statistical Analysis*

Dependent measures consisted of reaction time (RT), movement time to the first target (MT1), movement time from the first target to the second target (MT2), and pause time at the first target. RT was the interval from the presentation of the stimulus tone to the start of the movement to the first target. MT1 was measured as the interval between the start and end positions of movement 1 (i.e., the interval between when the stylus was lifted off the start location at a velocity above 15mm/s to when velocity in the same direction fell below 15mm/s; stylus touch down). The calculation of MT2 was identical to that of MT1 with the exception that the time interval was between the start and stop locations of movement 2. Pause time was the interval between the stylus touching down at target 1 and when it was lifted from target 1. As an overall measure of spatial variability in the x-y plane, we calculated ellipse areas at the end of the first and second movement using the within-participant standard deviations of position along the y and x axis as the radii ($\pi \times SDy \times SDx$) (Hansen, Elliott and Khan, 2008).

Separate 4 Target Size (Small-Small; Small-Large; Large-Small; Large-Large) × 3 Task (One target, Two target: Single limb, and Two target: Two limb) repeated measures ANOVAs were performed on RT, MT1 and ellipse area at Target 1, whilst a separate 4 Target Size (Small-Small; Small-Large; Large-Small; Large-Large) × 2 Task (Two target: Single limb, and Two target: Two limb) repeated measures ANOVAs were

performed on MT2, pause time and ellipse area at Target 2. Tukeys HSD post hoc tests ($p < .05$) were performed on significant main effects and interactions.

## 3. Results

Trials in which RT was less than 100 ms or more than 700 ms were omitted from the analysis. This amounted to less than 3% of the trials. The means and *SD*s of all dependent measures for the 4 different task conditions are reported in Table 1.

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Insert Table 1 here

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### *3.1. Reaction time (RT)*

The analysis of RT revealed a main effect for Task that approached conventional levels of significance ($F_{(2,46)} = 3.18$, $p = .05$, $\eta^2 = .05$). Specifically, RTs were shortest in the One target task and longest in the Two target: Single limb task. There was no main effect for Target Size ($F_{(3,69)} = 1.78$, $p = .16$, $\eta^2 = .03$) nor a Target Size × Task interaction ($F_{(6,138)} = 1.08$, $p = .38$, $\eta^2 = .01$).

### *3.2. Movement time to the first target (MT1)*

As shown in Figure 2, the analysis of MT1 revealed main effects for Target Size ($F_{(3,69)} = 59.05$, $p < .05$, $\eta^2 = .61$) and Task ($F_{(2,46)} = 9.80$, $p < .05$, $\eta^2 = .03$) , as well as a Target Size × Task interaction ($F_{(6,138)} = 3.26$, $p < .05$, $\eta^2 = .01$). Breakdown of the interaction revealed that when the first target was small, there was no difference in MT1 between the One target, Two target: Single limb and Two target: Two limb tasks.

However, when the first target was large, MT1 was shorter in the One target compared to the Two target: Single limb and Two target: Two limb tasks. There was no difference between the Two target: Single limb and Two target: Two limb tasks.

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Insert Figure 2 here

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*3.3. Pause time*

The analysis of pause time revealed a main effect for Task ($F_{(1,23)} = 18.40$, $p < .05$, $\eta^2 = .20$) and for Target Size ($F_{(3,69)} = 25.29$, $p < .05$, $\eta^2 = .32$). In all target size conditions, the single limb task had longer pause times than the two limb task (see Figure 3). Pause times were also longer in the small compared to large first target conditions. A significant Task × Target Size interaction ($F_{(3,69)} = 3.60$, $p < .05$, $\eta^2 = .01$) indicated that the difference in pause times between the small and large first target conditions was greater in the single (66 ms) compared to two limb (48 ms) task.

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Insert Figure 3 here

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*3.4. Movement time from the first target to the second target (MT2)*

A significant main effect for Task ($F_{(1,23)} = 17.24$, $p < .05$, $\eta^2 = .04$) indicated that MT2 was significantly shorter in the Two target: Single limb task compared to the Two target: Two limb task. A significant main effect for Target Size ($F_{(3,69)} = 19.89$, $p < .05$, $\eta^2 = .44$) also indicated that MT2 was shorter when the second target was large compared

to when it was small. The was no Target Size × Task interaction ($F_{(3,69)} = 2.39$, $p = .08$, $\eta^2 = .01$).

*3.5. Variability ellipse areas at the first target*

The analysis of ellipse areas at Target 1revealed a main effect for Task ($F_{(2,46)} = 3.76$, $p < .05$, $\eta^2 = .01$), Target Size ($F_{(3,69)} = 49.48$, $p < .05$, $\eta^2 = .42$), and a Task × Target Size interaction ($F_{(6,138)} = 3.43$, $p < .05$, $\eta^2 = .04$). As would be expected, EA1 was significantly less when the first target was small compared to large (see Figure 4). For the Small-Small, Small-Large and Large-Large target size conditions, there were no differences in variability between the One target, Two target: Single limb and Two target: Two limb tasks. For the Large-Small condition, variability ellipse areas were smaller in the Two target: Single limb and Two target: Two limb tasks compared to the One target task. There was no difference in variability between the Two target: Single limb and Two target: Two limb tasks for the Large-Small condition.

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Insert Figure 4 here

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*3.6. Variability ellipse areas at the second target*

The analysis of ellipse areas at Target 2 revealed a main effect for Task ($F_{(1,23)} = 11.98$, $p < .05$, $\eta^2 = .09$) and Target Size ($F_{(3,69)} = 14.63$, $p < .05$, $\eta^2 = .34$). Specifically, the Two target: Two limb task had larger ellipse areas at the end of the second movement compared to the Two target: Single limb task. Variability ellipses were also smaller

when the second target was small compared to large. No Task × Target Size interaction was revealed ($F_{(3,69)} = 1.84$, $p = .15$, $\eta^2 = .02$).

**4. Discussion**

Increasing the number of targets has been shown to increase the time taken to initiate (Khan et al., 2006; Khan, Mourton, Buckolz & Franks, 2007) and execute (Adam et al., 2000; Fischman & Reeve, 1992; Glencross, 1980; Khan et al., 2010) the first segment in a sequence. The increase in the execution time of the first segment (i.e., one-target advantage) has been explained via both the movement constraint hypothesis and the movement integration hypothesis. The movement constraint hypothesis is based on the idea that variability at the first target must be constrained in order to meet the accuracy demands at the second target while the movement integration hypothesis proposes that overlapping control processes associated with implementing the second segment during the execution of the first are the cause of longer movement times to the first target. Although the mechanisms responsible for the one-target advantage differ between the movement constraint hypothesis and movement integration hypothesis, recent evidence suggests that processes underlined in both hypotheses may explain how segments in a sequence are integrally linked (Khan et al., 2011).

While most research on sequential aiming movements has been performed employing a single limb, the one-target advantage has been observed for movements in which there is a switch between limbs at the first target (Khan et al., 2010; Lawrence et al., 2013). The emergence of the one-target advantage for two limb movements has two important implications. First, it points to a central locus underlying the one-target advantage. If the one-target advantage was due to peripheral factors, it should not be

present when the two segments are performed with different effector systems. Second, although the movement constraint hypothesis may account for the one-target advantage in single limb movements, it cannot explain the one-target advantage for two limb responses. This is because when the limb is switched, the starting point of the second segment does not depend on the end location of the first segment. Hence, variability at the first target should have no relevance for accuracy at the second target. The purpose of the present study was to further our understanding of the processes underlying the integration between movement segments by exploring similarities and differences between single and two limb movements. Specifically, the sizes of both the first and second targets were manipulated in order to test the underlying assumptions of the movement constraint hypothesis and movement integration hypothesis for both single and two limb movements.

Consistent with past research (Khan et al., 2010; Lawrence et al., 2013), the results of the present study indicated that the one-target advantage emerged for both the single and two limb tasks when the first target was large. Also, the magnitude of the one-target advantage was the same for both the single and two limb tasks. This finding suggests that the one-target advantage originates at a central (e.g., retrieval of motor programs from a buffer) rather than peripheral level (e.g., activation of specific neuro-muscular effectors) and reflects general dual-tasks costs (Oliveira & Ivry, 2008). If the one-target advantage was due to peripheral factors, the magnitude of the one-target advantage would have been reduced in the two limb task where there was a transition between largely distinct effector systems at the first target. Khan et al. (2010) have suggested that for both single and two limb tasks, the timing of the implementation of the

second movement remains crucial in order to ensure an efficient and smooth transition between response elements. Hence, it may be the central processes associated with timing the implementation of the second segment during the execution of the first segment that are responsible for the interference that causes an increase in movement time to the first target.

As expected, the one-target advantage did not emerge in the single limb condition when the first target was small. Consistent with past research, pause times at the first target were increased when the accuracy demands were increased (e.g., Adam et al, 2000). The increased pause times likely disrupted the transition and integration between the two movements causing the segments to be controlled and executed as independent units (Adam et al., 2000; Adam & Paas, 1996; Adam et al., 1995; Rand & Stelmach, 2000). Interestingly, the one-target advantage was also not present for the two limb task when the first target was small. One might have expected that the one-target advantage would emerge when the limbs are switched at the first target since the initiation of the second limb should not depend on accuracy at the first target. Hence, an efficient transition between the first and second segments might still have been possible since the second segment involves a relatively distinct effector system. Although pause times were shorter for the two compared to single limb task, pause times were longer for the smaller targets compared to large targets in both the single and dual limb conditions. Hence, the principles underlying the one-target advantage seem to be consistent between the single and two limb tasks. As suggested above, it is difficult for the movement constraint hypothesis to explain the one-target advantage for the two limb condition. However, along the lines of the movement integration hypothesis, the results again point to a central

locus of the one-target advantage and the timing of implementation of the second segment as the source of interference that leads to the one-target advantage (Khan et al., 2010). When aiming movements are performed to small targets, the attention demands associated with the use of vision likely become so high that there is no capacity for implementing the pre-programmed second segment during execution of the first (Khan et al. 2011). Hence, with small targets and associated long pause times, the implementation of the second segment occurs after the execution of the first segment. With the increase in pause times, the two segments in a two-target sequence are performed as separate and independently controlled units and therefore the one-target advantage does not emerge regardless of whether the two segments are performed with the same or different limbs. It should be noted that while pause times were greater for small compared to large first targets in both the single and two limb conditions, the effect of target size was greater in the single compared to two limb condition. This implies the magnitude of the resulting interference from central resources and hence the delay in implementing the second element was greater in the single compared to two limb condition when accuracy demands were high at the first target.

The present study also examined the effect of varying the size of the second target on variability at the first target. According to the movement constraint hypothesis (Fischman & Reeve, 1992), movements to the first target are constrained in order to be accurate at subsequent targets. This is based on the premise that spatial variability increases as a movement progresses (for a review, see Khan et al., 2006). Along these lines, Sidaway et al. (1995) have shown that the accuracy demands of the second target affect variability at the first target. Specifically, when accuracy demands were higher at

the second target variability at the first was reduced. In the present study, it was expected that for single limb movements variability at the first target would be constrained when the second target was small. Conversely, when the first and second movement segments were performed with separate limbs, it was expected that variability would not be constrained at the first target since the end location of the first movement was irrelevant to the start position of the second movement. The results of the present study supported the proposal of Sidaway et al. since variability at the first large target was reduced in conditions where the second target was small in the single limb condition. However, variability was also reduced at the first large target when the second target was small in the two limb condition. This was surprising since the two segments were performed with different limbs and hence accuracy at the second target should not depend on variability at the first target. Hence, the constraining of movement endpoints at the first target in the two limb tasks could not be explained by the movement constraint hypothesis. It may be that a central representation or the coding of accuracy demands at the second target has a non-specific influence across limbs that impacts variability at the first target regardless of which limb is used.

**5. Conclusion**

The present study has further shown the robustness of the one-target advantage for single and two limb aiming tasks. The effects of manipulating target size were generally similar for both the single and two limb conditions. The one-target advantage emerged when the first target was large but was not when it was small, regardless of the number of effectors involved. Also, reducing the size of the second target had the effect of reducing variability at the first target for both the single and two limb conditions.

Along the lines of the movement integration hypothesis, these results suggest a central locus underlying the one-target advantage and the functional dependency between segments in a target sequence regardless of whether the segments are performed with one or two limbs.

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| | | Task | | |
|---|---|---|---|---|
| | | 1T | 2T1L | 2T2L |
| RT | L-L | 329 (*61*) | 345 (*70*) | 343 (*75*) |
| (ms) | L-S | 316 (*58*) | 341 (*89*) | 327 (*67*) |
| | S-L | 322 (*59*) | 326 (*84*) | 330 (*83*) |
| | S-S | 320 (*67*) | 341 (*73*) | 334 (*77*) |
| MT1 | L-L | 298 (*61*) | 328 (*53*) | 324 (*58*) |
| (ms) | L-S | 318 (*69*) | 360 (*79*) | 352 (*70*) |
| | S-L | 410 (*83*) | 422 (*74*) | 417 (*71*) |
| | S-S | 422 (*84*) | 432 (*70*) | 417 (*67*) |
| PT | L-L | | 81 (51) | 51 (26) |
| (ms) | L-S | | 97 (69) | 51 (32) |
| | S-L | | 149 (87) | 103 (71) |
| | S-S | | 160 (89) | 94 (60) |
| MT2 | L-L | | 306 (*52*) | 344 (*83*) |
| (ms) | L-S | | 414 (90) | 422 (*94*) |
| | S-L | | 335 (91) | 365 (*109*) |
| | S-S | | 405 (*78*) | 440 (*86*) |
| EA1 | L-L | 30 (*13*) | 33 (*13*) | 27 (*15*) |
| ($mm^2$) | L-S | 33 (*16*) | 23 (*11*) | 24 (*13*) |
| | S-L | 14 (*7*) | 13 (*10*) | 14 (*8*) |
| | S-S | 14 (*8*) | 12 (*7*) | 13 (*9*) |
| EA2 | L-L | | 37 (*21*) | 50 (*42*) |
| ($mm^2$) | L-S | | 14 (*7*) | 23 (*13*) |
| | S-L | | 24 (*12*) | 41 (*24*) |
| | S-S | | 18 (*16*) | 22 (*13*) |

Table 1. Means and *SDs* of reaction time (RT), movement time to the first target (MT1), pause time (PT), movement time to the second target (MT2), variability ellipse area at the end of movement 1 (EA1), and variability ellipse area at the end of movement 2 (EA2) for the One target (1T), Two target: Single limb (2T1L) and Two target: Two limb (2T2L) tasks in the 4 target size conditions (large-large = L-L; large-small = L-S; small – large = S-L; small-small = S-S).

Figure 1. Panel a: start position of limbs/stylus and target locations for all trials. Panel b: arrangement of targets and the combination of sizes (Small-Small; Large-Small; Large-Large; Small-Large). Panel c: the three different movement tasks (One target, Two target: Single limb, Two target: Two limb).

Figure 2. Mean movement times and *SDs* (error bars) to the first target as a function of task (1T = Single target; 2T1L = Two target: Single limb; 2T2L = Two target: Two limb) and target size (Small-Small; Large-Small; Large-Large; Small-Large).

Figure 3. Mean pause times and *SDs* (error bars) as a function of task (2T1L = Two target: Single limb; 2T2L = Two target: Two limb) and target size (Small-Small; Large-Small; Large-Large; Small-Large).

Figure 4. Mean ellipse areas and *SDs* (error bars) at the end of the first movement as a function of task (1T = One target; 2T1L = Two target: Single limb; 2T2L = Two target: Two limb) and target size (Small-Small; Large-Small; Large-Large; Small-Large).

Figure 1.

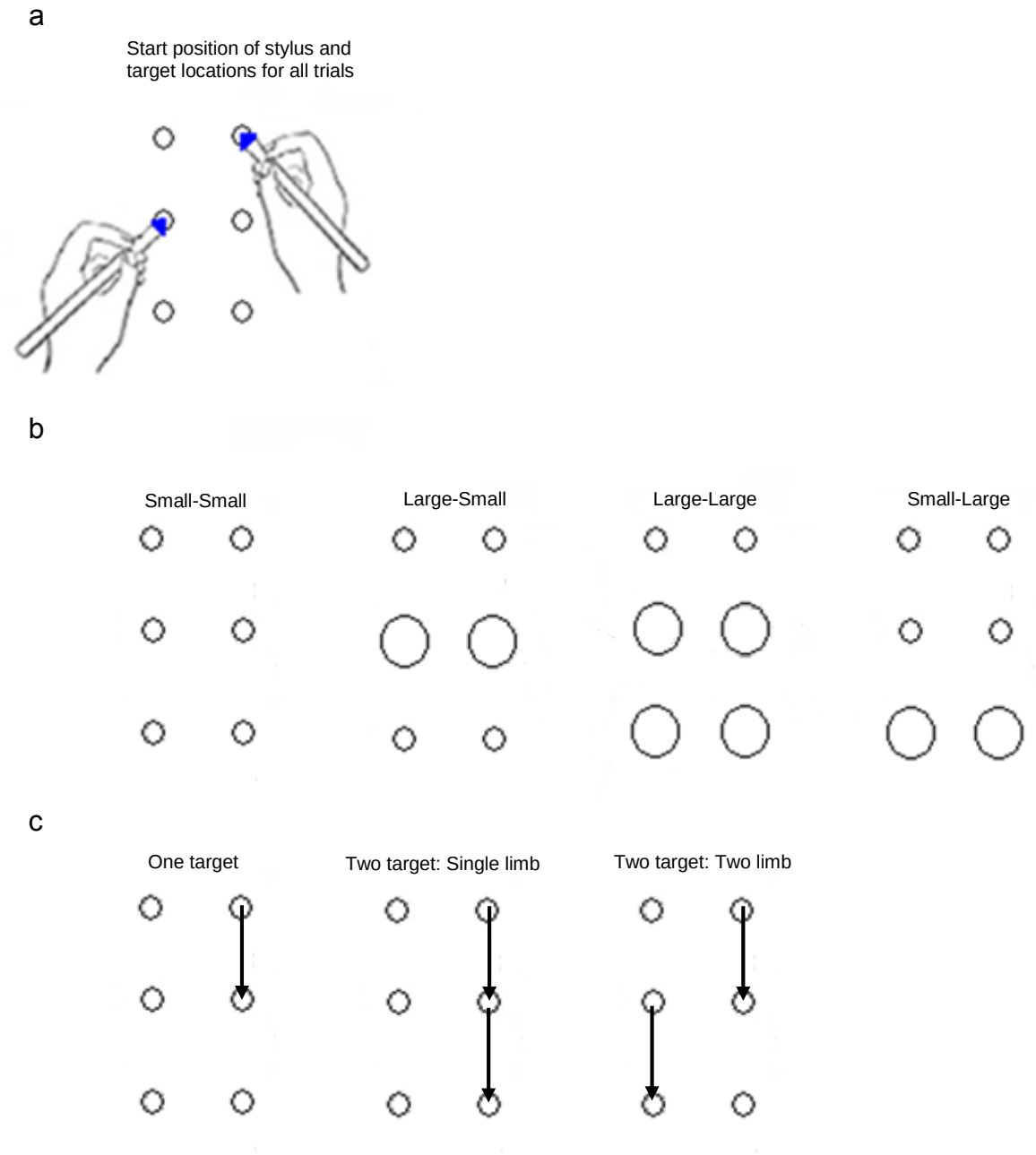

a
Start position of stylus and target locations for all trials
b
Small-Small
Large-Small
Large-Large
Small-Large
c
One target
Two target: Single limb
Two target: Two limb

Figure 2.

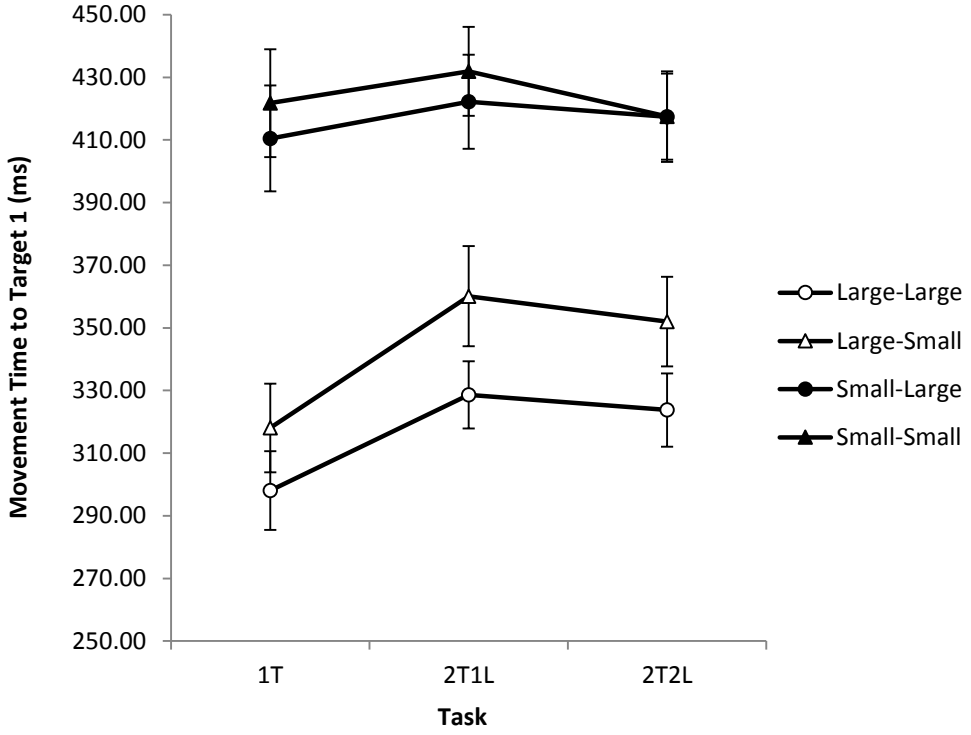

450.00
430.00
410.00
390.00
370.00
350.00
330.00
310.00
290.00
270.00
250.00
Movement Time to Target 1 (ms)
1T
2T1L
2T2L
Task
Large-Large
Large-Small
Small-Large
Small-Small

Figure 3.

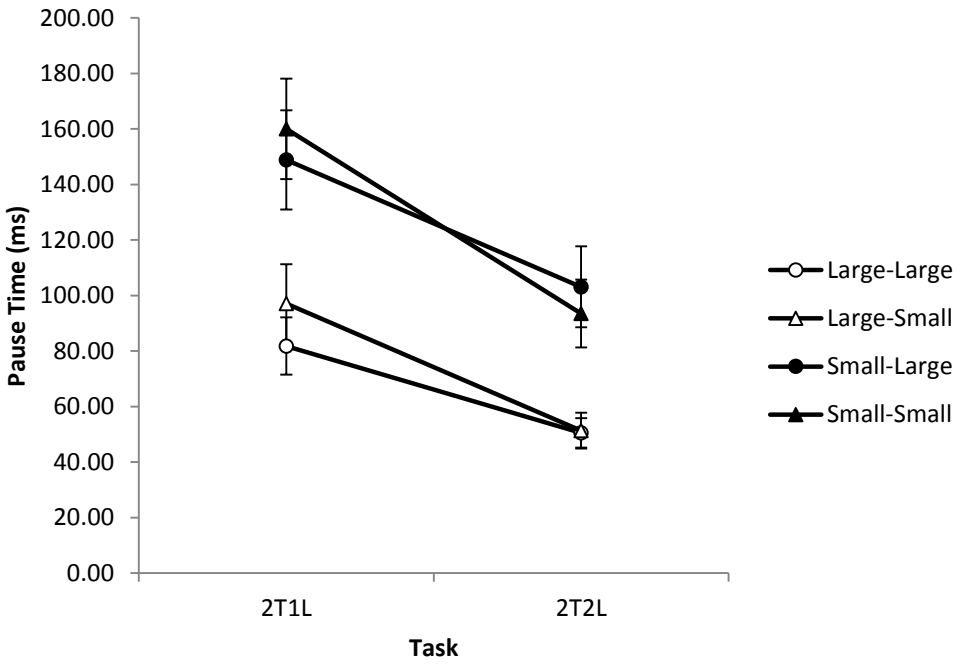
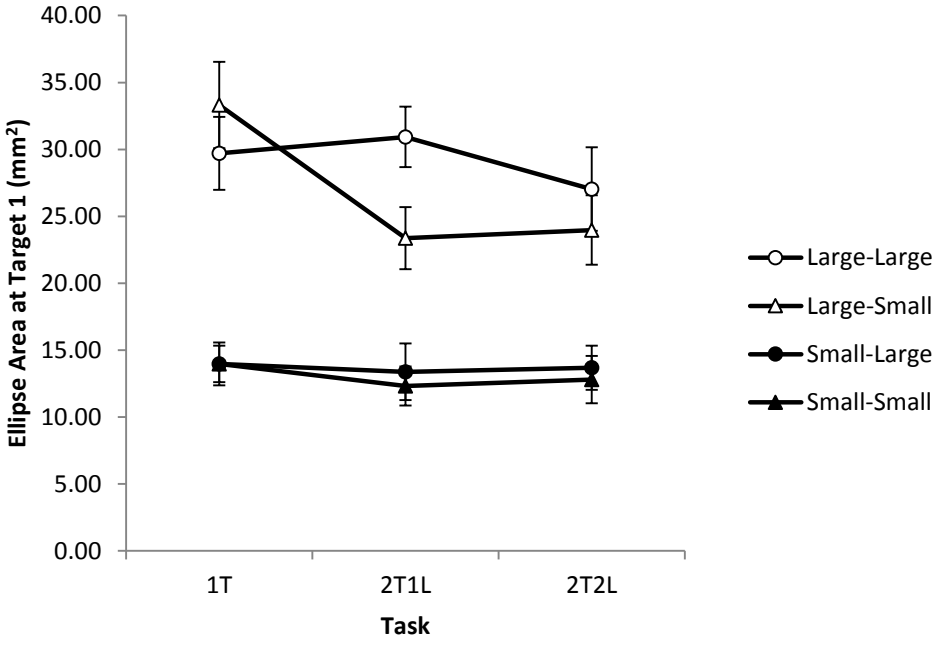

200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Pause Time (ms)
2T1L
2T2L
Task
Large-Large
Large-Small
Small-Large
Small-Small

Figure 4.


40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Ellipse Area at Target 1 (mm²)
1T
2T1L
2T2L
Task
Large-Large
Large-Small
Small-Large
Small-Small